(12) UK Patent Application (19) GB (11) 2 019 486 A

(21) Application No 7918036
(22) Date of filing 23 May 1979
(23) Claims filed 23 May 1979
(30) Priority data
(31) 9095/78
(32) 7 Mar 1978
(33) United Kingdom (GB)
(43) Application published
31 Oct 1979
(51) INT CL²
F04B 9/12//43/00
(52) Domestic classification
F1A 1C2 1C6A
(56) Documents cited
GB 794781
(58) Field of search
F1A
F1R

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(54) Pumps

(57) A pump having a chamber 13 partially filled with a liquid 11 to present a vapour/liquid interface between two regions H, C of the pump at different temperatures. A buoyant body 10 in the liquid is arranged to oscillate and reciprocate the interface between the regions so as to vary the vapour pressure on the liquid, and as a result the oscillatory motion of the body 10 displaces the liquid against a load. A bellows may separate the liquid in chamber 11 from the pumped liquid.

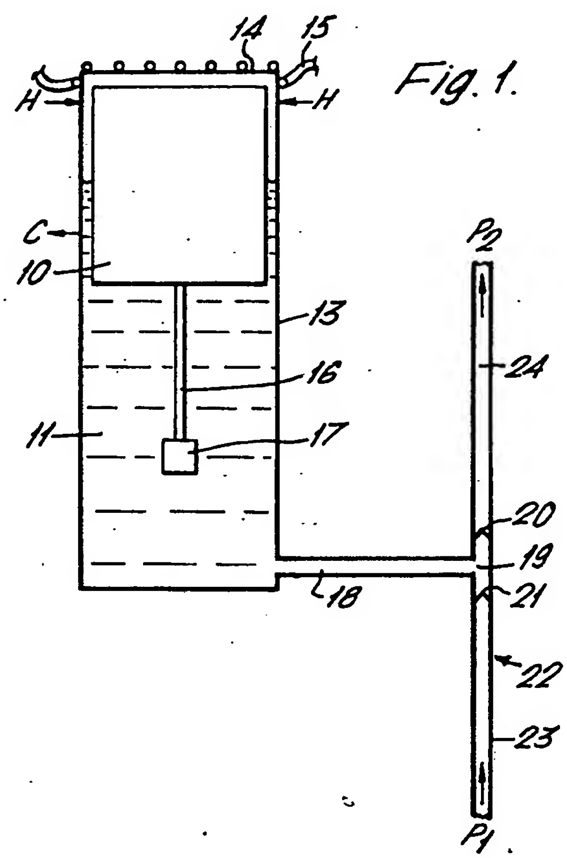

Fig. 1.

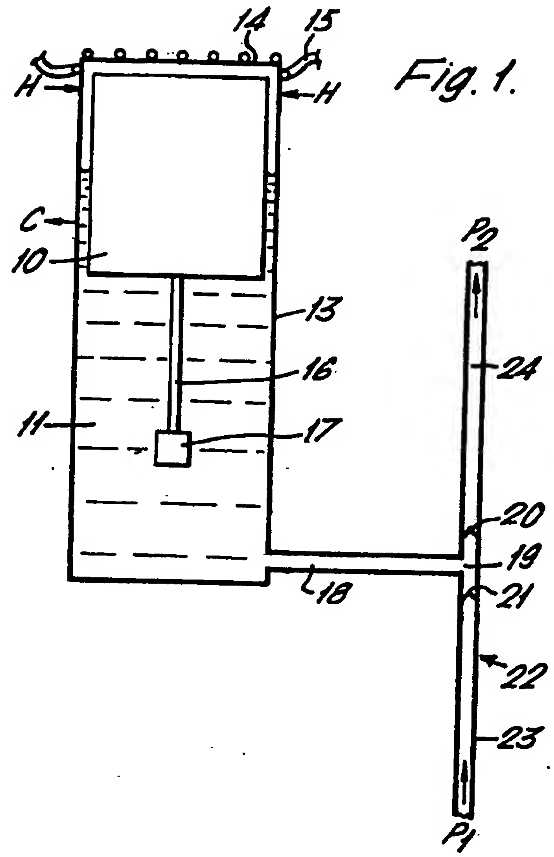

Fig. 1.

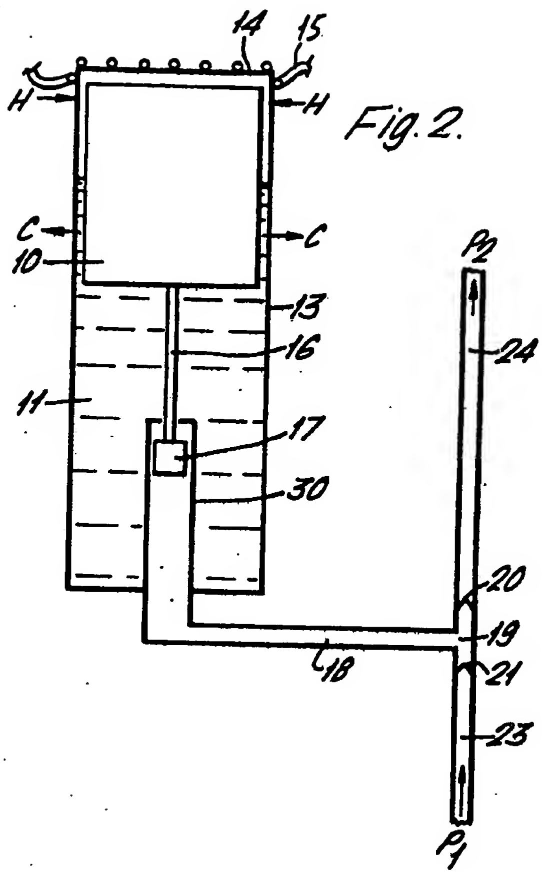

Fig. 2.

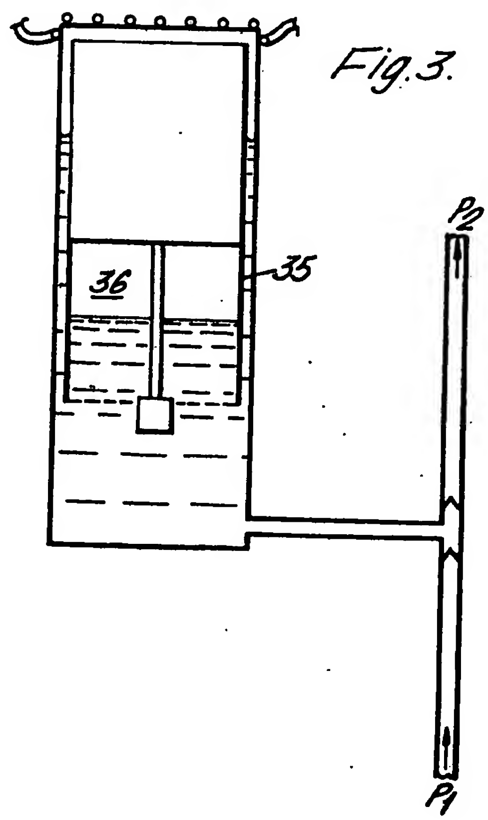

Fig. 3.

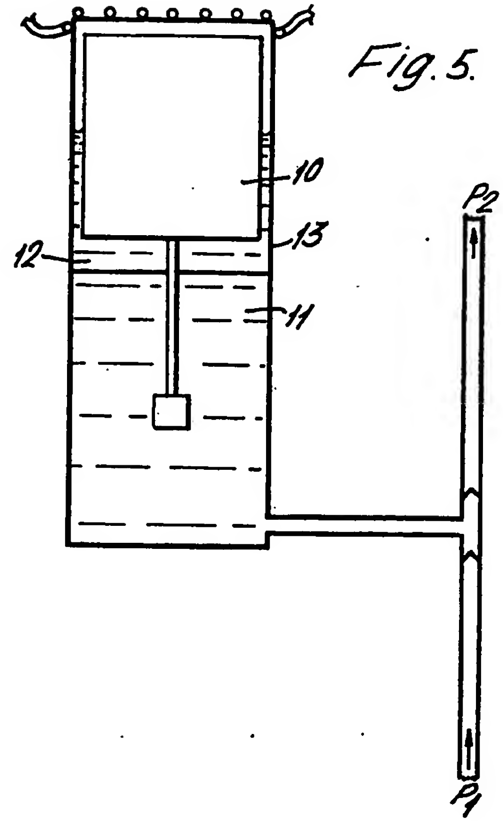

Fig. 5.

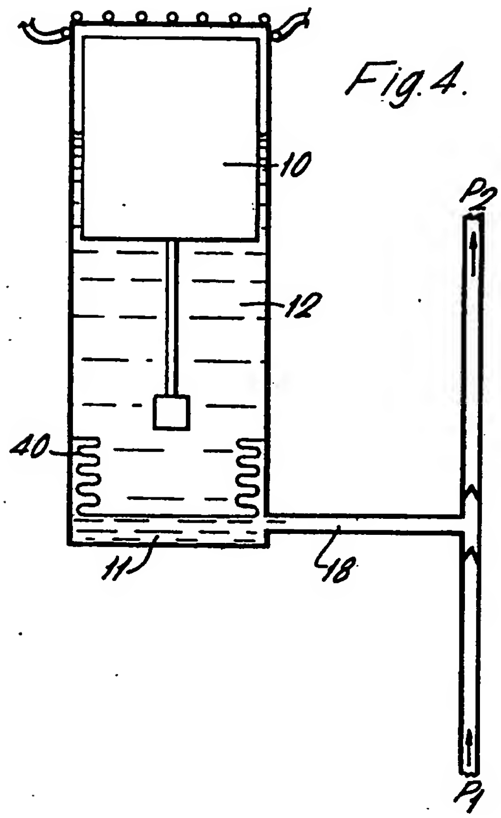

Fig. 4.

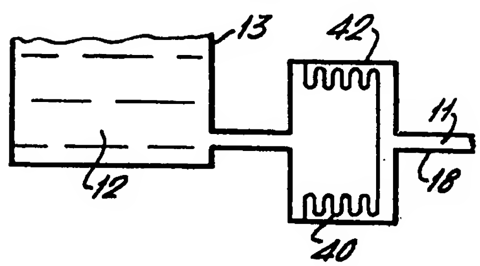

Fig. 4a.

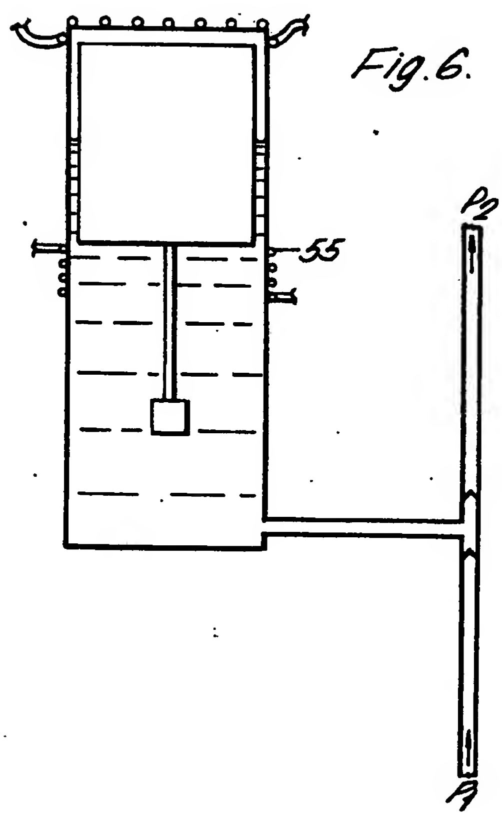

Fig. 6.

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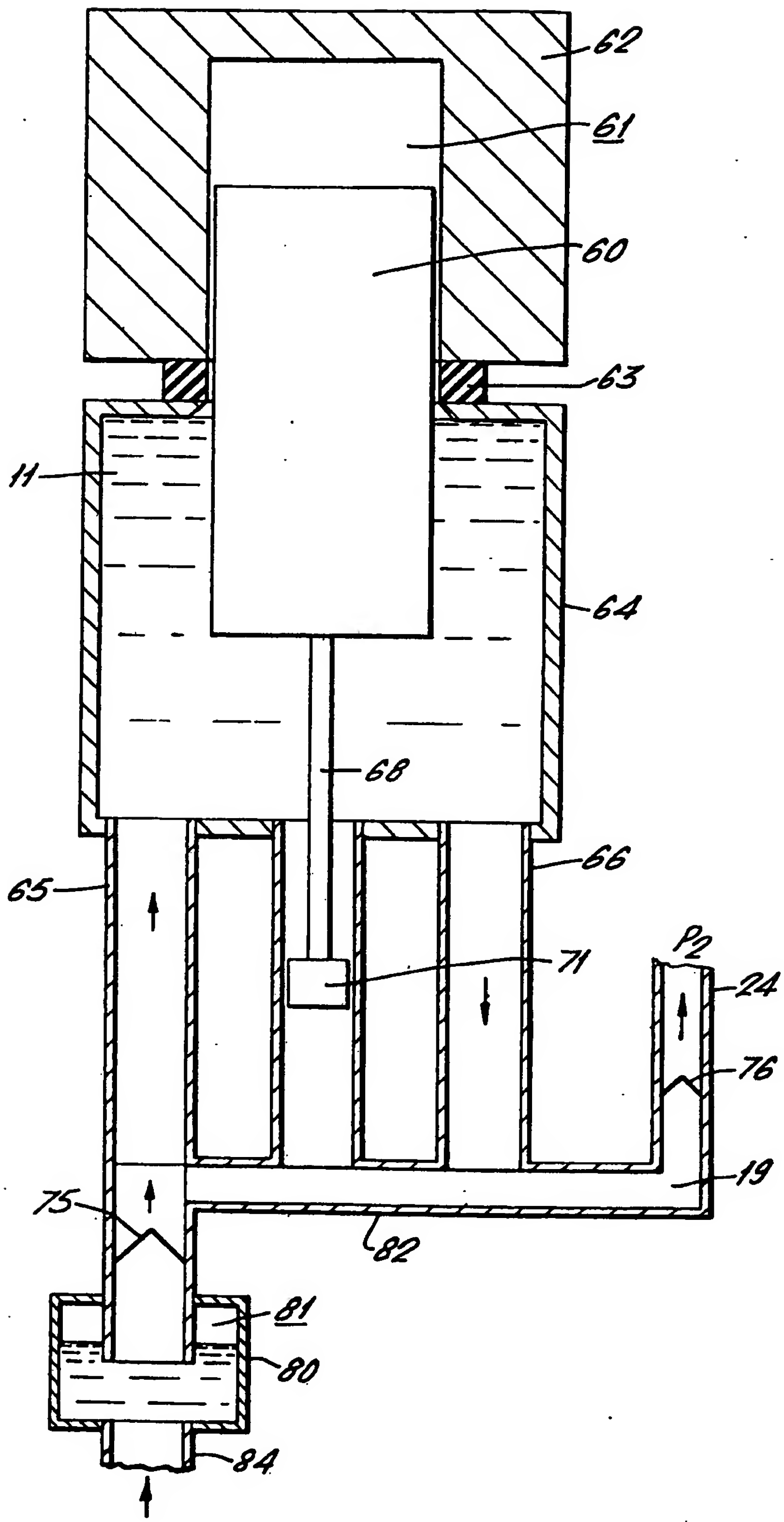
Fig. 7.



SPECIFICATION

Improvements in or Relating to Pumps

This invention relates to pumps and pumping systems.

According to one aspect of the present invention, a pumping system comprises, a chamber having two regions at different temperatures and partially filled with a liquid to provide a liquid/vapour interface thereof between the regions, and a displacement means partially immersed in the liquid, the displacement means in operation of the system having a motion such as to vary the degree of immersion thereof and reciprocate said interface from one region to the other region, thereby to vary the vapour pressure on the liquid so that said motion of the displacement means displaces the liquid against a load.

According to another aspect of the present invention, a pump comprises.

(a) a chamber adapted to contain a liquid to provide a liquid/vapour interface in the chamber;

(b) a first region of the chamber;

(c) a second region of the chamber such as to extend below the first region in use of the pump, said regions being arranged to be different temperatures; and

(d) a displacement means within the chamber adapted to be partially immersed in the liquid, the displacement means being movable in a manner to vary the degree of immersion thereof and reciprocate said interface between said first and said second regions, and thereby to vary the vapour pressure on the liquid, so that in operation of the pump said motion of the displacement means displaces the liquid against a load.

Preferably, the regions are provided by means for producing a temperature gradient in the chamber, and the hotter of the two regions may be at one end of the chamber which one end may be above or below the displacement means.

The chamber and the displacement means may be shaped with respect to each other to arrange that said liquid/vapour interface is of greater surface area at the cooler of the two regions. Preferably, the higher vapour pressure is above atmospheric pressure and the lower vapour pressure is below atmospheric pressure.

The load on the liquid may comprise the pressure of a fluid which may comprise a gas, or a liquid, or a mixture of a gas and a liquid.

The liquid in the chamber may float on another liquid of lower volatility.

Desirably, the displacement means comprises a cylindrical body adapted to define a relatively narrow annular gap between the adjacent surface of a cylindrical said chamber.

Preferably, means are provided to excite the motion of the displacement means.

The invention will now be further described by way of example only with reference to the accompanying drawings, in which:—

Figure 1 shows a diagrammatic sectional representation of a vapour cycle pump;

Figures 2 to 6 each shows a diagrammatic sectional representation of a modified form of the vapour cycle pump of Figure 1, Figure 4*a* showing a fragmentary diagrammatic sectional view of a modification of the pump of Figure 4; and

Figure 7 shows a sectional representation of another form of vapour cycle pump.

Referring now to Figure 1, in the vapour cycle pump shown which is of circular form in section, a cylindrical displacer 10 floats on a liquid 11 (e.g. water) inside a cylinder 13 whose upper end 14 is closed. The upper end 14 of the cylinder 13 is heated by a heat transfer medium such as boiling water under pressure, e.g. a water filled heat pipe, in heat transfer pipes 15, the lower end of the cylinder being kept cool by the liquid 11. The displacer 10 has an elongate keel in the form of a keel rod 16 having a cylindrical weight 17 at its lower end to keep the displacer 10 upright.

A duct 18 leads from the lower end of the cylinder 13 to a pumping chamber 19 having an upper non-return valve 20 and a lower non-return valve 21, the pumping chamber 19 being incorporated in a pumping line 22 having a suction duct 23 at a pressure P1 and a discharge duct 24 at a pressure P2.

When unheated, the whole of the space between the displacer 10 and the cylinder 13 is filled with the liquid 11, and the top of the displacer 10 is adjacent to the upper end 14 of the cylinder 13. As the heat transfer fluid flows through the heat transfer pipes 15, the heat applied causes the pressure of the liquid 11 in the cylinder 13 to rise until it reaches pressure P2 when the upper non-return valve 20 opens allowing liquid 11 to be expelled through the discharge duct 24. The liquid 11 at the upper end 24 of the cylinder 13 then vapourises filling the space at the upper end 14 of the cylinder 13 with vapour and driving the surface of the liquid at the liquid-vapour interface downwards to a level on the wall of the cylinder 13 where the temperature is such that the vapour pressure of the liquid 11 is just equal to the pressure of the liquid 11 inside the cylinder 13, i.e. P2.

Considering now the oscillatory or reciprocating movement of the displacer 10, as it moves downwards the space above it is filled by vapour evaporated from the liquid interface to maintain the vapour pressure at P2 so that liquid 11 displaced by the displacer 10 flows through the duct 18 and upper non-return valve 20 into the discharge duct 24. When the displacer 10 reaches the bottom of its downward movement and begins to return, this reversal closes the upper non-return valve 20 and drives the liquid interface in the cylinder 13 downwards exposing the cooler lower surface of the cylinder 13 to the vapour, the vapour pressure then drops rapidly causing the pressure inside the cylinder to fall to P1 when the lower non-return valve 21 opens and liquid 11 flows through the suction duct 23 and duct 18 into the cylinder 13.

As the displacer 10 continues upwards, the liquid interface in the cylinder 13 will remain at a

level where the temperature produces a vapour pressure equal to P1, and liquid 11 will continue to be drawn into the cylinder 13 until the displacer 10 reaches the top of its oscillatory movement. The displacer 10 then starts moving downwards again when the lower non-return valve 21 closes driving the liquid interface in the cylinder 13 upwards and raising the vapour pressure until the upper non-return valve 20 opens and the cycle is repeated again.

Considering now the excitation of the displacer 10, as the displacer 10 is buoyant in the liquid 11, the liquid 11 exerts a restoring force on the displacer 10 tending to bring it back to a position at which the liquid interface is at a given level on the wall of the cylinder 13. Theoretically if the heated end 14 and cooler end of the cylinder 13 were close together so that the level of the liquid interface hardly changed during a cycle, then the displacer 10 would execute a damped sinusoidal motion, the damping being mainly due to the viscosity of the liquid 11.

In practice it would be necessary to separate the heated and cooled regions of the cylinder 13 by a significant distance to reduce heat loss by direct conduction. The liquid interface in the cylinder 13 will then be higher during the down stroke of the displacer 10 than during the up stroke, and this will produce a buoyancy force which opposes displacer velocity. If the displacer 10 is to execute a sustained oscillation, this buoyancy force must be opposed by another force which acts downwards when the displacer 10 is moving downwards and upwards when the displacer is moving upwards. Examples of vapour cycle pumps in which this effect is achieved are shown in Figures 2 and 3.

Referring now to Figure 2, the vapour cycle pump shown is identical to that shown in Figure 1 except that the weight 17 of the keel of the displacer 10 locates loosely in an upright duct 30 which connects with the duct 18 leading to the pumping chamber 19. When the displacer 10 moves either upwards or downwards, the drag of the liquid in flowing over the weight 17 provides the force necessary to oppose the abovementioned buoyancy force. Viscous losses are increased by the arrangement shown in Figure 2 and it relies on the pressure cycle being large enough to open and close the two non-return valves 20 and 21 respectively.

In alternative examples of a vapour cycle pump shown in Figure 3 to which reference is now made, a cylindrical skirt 35 is provided at the bottom of the displacer 10 to define a cavity 36 therewithin in which a gas such as air is entrained. In all other respects the vapour cycle pump shown in Figure 3 is identical to that shown in Figure 1. In operation as the pressure of the liquid 11 in the cylinder 13 rises and the displacer 10 moves downwards, the volume of the entrained gas reduces with a consequent reduction in the buoyancy of the displacer 10 which off-sets the above mentioned upward buoyancy force due to the rise in the liquid interface in the cylinder 13. The reverse takes place on the upward stroke of the displacer 10 when the pressure of the liquid 11 in the cylinder 13 reduces.

The vapour cycle pumps described in Figures 1 to 3 may not be self-starting although in a practical pump unlike an ideal pump, the phase relationships of the components of the pump may be more favourable to self-starting.

In the examples shown in Figures 1 to 3, the operation of a vapour cycle pump according to the invention has been described in relation to the use of the same liquid to operate the pump as that to be pumped.

As an alternative, the pump may be operated as shown in Figures 4 and 5 to which reference is made by a different liquid. In Figure 4 a volatile liquid 12 such as Freon is shown above the liquid 11 to be pumped and separated from the liquid 11 by a flexible member, for example a Rhilips "Rollsock" seal 40 attached to the lall of the cylinder 13 below the displacer 10. As an alternative to the use of a "Rollsock" seal 40, a flexible diaphragm (not shown) may be used, and the "Rollsock" seal 40 may be inserted as shown in Figure 4*a*, in an enlarged portion 42 of the duct 18.

In Figure 5, a volatile liquid 12 such as hexane, of lower specific gravity than the liquid 11, is allowed to float on the liquid 11.

By use of a volatile liquid 12 to operate the pumps of Figures 4 and 5 respectively, a higher vapour pressure can be provided at lower temperatures inside the cylinder 13 than that exerted by a less volatile liquid 11 to be displaced by the pump.

It will be understood that the displacer 10 may be inverted in the cylinder 13 and the lower end of the cylinder 13 heated, the displacer 10 being connected to the bottom of the cylinder 13 by a tension spring (not shown) to provide a positive restoring force on the displacer 10 to oppose the buoyancy force on the displacer 10. In such an inverted arrangement there is no need to prevent air from entering the heated space since it will rise above the liquid 11 in the cylinder 13. In the arrangement shown in Figures 1 to 5 the operating frequency of oscillation of the displacer 10 may be increased above that due to the natural buoyancy of the displacer by attaching restoring springs (not shown) to the displacer 10.

Although the inner surface of the cylinder 13 has been shown as a smooth surface, this surface may be shaped to provide extended heat transfer surfaces.

Instead of relying on the liquid 11 in the cylinder 13 to cool the walls of the cylinder 13, a cooling vessel or coils may be placed around the cylinder 13 as shown in Figure 6 to which reference is now made. In Figure 6 the vapour cycle pump is identical to the pump shown in Figure 1 except that the cylinder 13 is arranged to be cooled lower down the cylinder 13 by cooling water in heat transfer pipes 55 coiled around the cylinder 13.

An arrangement in which a cooling vessel through which the pumped liquid 11 passes is used to cool the cylinder 13 is shown in Figure 7 to which reference is now made.

In Figure 7 a displacer 60 is disposed within a cylinder 61 defined by a heated metal block 62 and a thermal insulating spacer 63 of a material such as Pyrex or PTFE, and extends into a cooling vessel 64 having an inlet duct 65 and an outlet duct 66 for liquid 11 into and out of the cooling vessel 64. A keel rod 68 extends from the displacer 60 into a guide duct 70 and has a guide in the form of a weight 71 which provides lateral stability for the lower end of the displacer 60.

The inlet duct 65 is connected to and extends a short distance into a vessel 80 which contains a small quantity of air trapped in a space 81 above the level of the liquid 11 in the vessel 80 and has a suction column 84. The inlet duct 65 which extends from the bottom of the vessel 80, the outlet duct 66 and the guide duct 70 connect with a branch duct 82. An inlet non-return valve 75 is provided in the inlet duct 65 and an outlet non-return valve 76 in the branch duct 82.

The pump shown in Figure 7 operates in a similar manner to the pumps shown in Figures 1 to 6, and the viscous drag of the liquid 11 about the weight 71 provides a force to oppose the buoyancy force on the displacer 60 as described in relation to Figure 2.

An important advantage of using a cooling vessel 64 of larger diameter than the cylinder 61 is that, as soon as the liquid/vapour interface falls below the top of the vessel 64, the area of the liquid/vapour interface increases abruptly, greatly increasing the rate of condensation onto the liquid 11 surface.

One advantage of the use of the vessel 80 having a trapped volume of air is that the air acts as a buffer so as to make the flow of the liquid 11 up the inlet duct 65 into the cooling jacket 64 nearly continuous during the upward movement of the displacer 60. Without this, the inertia of the liquid 11 in the suction column 84, would cause the vapour pressure to fall to a very low level during the start of the suction stroke.

As an alternative to relying on the use of the viscous drag on the weight 71 to provide a force to oppose the buoyancy force on the displacer 60, the arrangement shown in Figure 3 of providing a trapped volume of gas in a skirt (not shown) at the bottom of the displacer 60 may be used, the provision of the keel rod 68 still being necessary but the weight 71 could be shaped to provide fins extending to the inside of the guide duct 70 to provide lateral stability for the displacer 60 without introducing substantial viscous drag.

Liquid 11 inertia in the discharge duct 24 results in most of the vapour being generated during the end part of the stroke, so that efficiency is increased by using the expansion work of the vapour.

It will be understood that the level of the liquid interface around the displacer of Figures 1 to 7 is self-regulating to provide whatever pressure the load demands (subject to the limit set by the vapour pressure available at the heated end of the cylinder). It is this feature which enables a relatively simple pump to be provided according to the invention.

The vapour cycle pump of the invention may be heated by alternative means, such as solar-powered applications, for example in solar-powered desalination.

In such an application in which the vapour cycle pump is powered from a solar collector, salt water could be introduced through a pressure reducing valve into an evaporator held at a low pressure by the suction from the pump, and the resultant vapour in the evaporator pressurised by the pump to condense the vapour as the pressure rises so that the distillate issues at atmospheric pressure.

In order to reduce heat losses, the displacer of Figures 1 to 7 may comprise thermal insulating material, for example as a coating on a metal body or contained within a metal body.

The vapour cycle pump may be used to pump gases or a liquid containing a gas. In such an application, the duct between the cylinder of the pump and the pump chamber may extend upwardly above the cylinder and be connected to a manifold to which a downwardly extending gas pumping line is connected, and in this application a capillary bleed vent for air which might be trapped in the heated space in the cylinder may be connected to the manifold.

In some applications the presence of a gas such as air mixed with the vapour in the cylinder of the pump might be advantageous. For example, the partial pressures of the air and vapour would combine so that it may be possible to deliver water at above atmospheric pressure while keeping the heated end of the cylinder below 100°C, but as the partial pressure of the air will vary with the position of the displacer in the cylinder the useful displacer stroke may be substantially reduced.

It will be understood that although the invention has been described in relation to a load applied by a fluid, a reciprocating pumping system or device therefor according to the invention may be coupled to a mechanical link (not shown) to provide a reciprocating mechanical output. Alternatively, the space occupied by vapour in the cylinder 13 may communicate with a power absorber, such as a pumping chamber (not shown) operated by the pressure changes of the vapour, provided that this chamber is kept at a temperature above the condensation temperature of the vapour, otherwise vapour will condense in it, increasing heat loss.

It will be appreciated that the motion of the displacement means need not be a straight line and may, for example, be provided from a pivotal or rotary connection for the displacement means.

Claims

1. A pump comprising,

(a) a chamber adapted to contain a liquid to

provide a liquid/vapour interface in the chamber;

(b) a first region of the chamber,

(c) a second region of the chamber such as to extend below the first region in use of the pump, said regions being arranged to be at different temperatures; and

(d) a displacement means within the chamber adapted to be partially immersed in the liquid, the displacement means being movable in a manner to vary the degree of immersion thereof and reciprocate said interface between said first and said second regions and thereby to vary the vapour pressure on the liquid, so that in operation of the pump said motion of the displacement means displaces the liquid against a load.

2. A pump as claimed in Claim 1, wherein the displacement means comprises a cylindrical body adapted to provide a relatively narrow annular gap between the adjacent surface of a cylindrical said chamber.

3. A pump as claimed in Claim 1 or Claim 2, wherein the regions are provided by means for producing a temperature gradient in the chamber.

4. A pump as claimed in any one of the preceding Claims, wherein the regions are arranged so as to provide that the hotter of the two regions is at one end of the chamber and above the displacement means in use of the pump.

5. A pump as claimed in any one of Claims 1 to 3, wherein the regions are arranged to provide that the hotter of the two regions is at one end of the chamber and below the displacement means in use of the pump, andthe displacement means is urged towards said one end by resilient biasing means.

6. A pump as claimed in any one of the preceding Claims, wherein the chamber and the displacement means are shaped with respect to each other to provide that the liquid/vapour interface is of greater surface area at the cooler of the two regions.

7. A pump as claimed in any one of the preceding Claims, including means for exciting motion of the displacement means.

8. A pump as claimed in Claim 7, wherein the exciting means comprises means for applying a viscous drag on the motion of the displacement means.

9. A pump as claimed in Claim 7, wherein the exciting means comprises a cavity in the displacement means having a port means thereinto for the liquid at the lower end of the cavity and a gas entrained therein, so that the volume of the gas changes with the depth of immersion of the displacement means.

10. A pump as claimed in any one of the preceding Claims, wherein the displacement means comprises a thermal insulating material.

11. A pumping system comprising, a chamber having two regions at different temperatures and partially filled with a liquid to provide a liquid/vapour interface thereof between the regions, and a displacement means partially immersed in the liquid, the displacement means in operation of the system having a motion such as to vary the degree of immersion thereof and reciprocate said interface from one region to the other region, thereby to vary the vapour pressure on the liquid so that said motion of the displacement means displaces the liquid against a load.

12. A pumping system as claimed in Claim 11, including a vessel partially filled with a liquid and disposed above the chamber, and to which vessel the pumping system is connected to displace said liquid and thereby displace a gas above said liquid in the vessel, the vessel having an upwardly extending duct therefrom for the flow of the gas therethrough.

13. A pumping system as claimed in Claim 11, including solar collecting means for heating one of the regions, and an evaporator connectable to the pumping system for the desalination of salt water therein.

14. A pumping system as claimed in Claim 11, wherein said liquid is floating on another liquid of lower volatility.

15. A pumping system as claimed in Claim 11, wherein the pumping system is coupled to a mechanical link to provide a reciprocating mechanical output.

16. A vapour cycle pump substantially as hereinbefore described with reference to Figure 1, or Figure 2, or Figure 3, or Figures 4 and 4*a*, or Figure 6, or Figure 7 of the accompanying drawings.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1979. Published by the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.